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SUPERFUND INNOVATIVE TECHNOLOGY EVALUATION

Demonstration Bulletin

In Situ Steam Enhanced Recovery Process

Hughes Environmental Systems, Inc.

Technology Description: The Steam Enhanced Recovery Process (SERP) is designed to remove volatile compounds such as halogenated solvents and petroleum hydrocarbons, and semi-volatile compounds from contaminated soils *in situ*. The vapor pressures of most contaminants will increase by the addition of steam, causing them to become more volatile and mobile. The technology operates through wells drilled in the contaminated soil. Injection wells deliver high pressure steam (15 psig) to the soil, while extraction wells draw a vacuum on the soil. The pressure gradient drives the steam, water, and vaporized contaminants to the extraction wells where they can be removed for disposal or recycling. Figure 1 illustrates the operation of the process beneath the soil surface.

A site to be treated with *in situ* SERP must have predominantly medium to high permeability soils. A geological confining layer below the treatment depth and a confining layer above the treatment zone help to contain the flow of steam. Injection and extraction wells are arranged on the site in a pattern designed to promote even distribution of the steam. Site-specific factors determine the number of wells used, their arrangement on the site, their construction, and the above-ground process equipment to be used.

A full-scale SERP system with 35 injection wells and 38 extraction wells was used to treat a 2.3-acre area of soil up to 40 feet deep at the Rainbow Disposal site in Huntington Beach, California. This site was contaminated with diesel fuel compounds. Water for steam generation was pumped from an on-site deep water well, treated by ion exchange and the addition of chemicals, and heated in one of two natural gas-fired steam boilers. High pressure steam was delivered to all the injection wells using a manifold system. Air-lift pumps were used to remove accumulated oily water from the extraction wells, and a vacuum pump maintained a negative pressure on the soil and removed the vapors from each extraction well.

The heated liquid (condensate) from the extraction wells was routed to a heat exchanger used to pre-heat the boiler feedwater, and then treated in a gravimetric oil/water separator. The diesel phase from the separator was collected in a storage tank. The remaining water phase was then treated further using filtration and activated carbon before being discharged directly to an underground storm sewer. Liquids and particulates entrained in the extracted vapor were removed using a knock-out drum. The vapor stream was then treated in a thermal oxidizer unit which used electrical heating to oxidize the vapor before discharging it through a stack to the atmosphere.

The full-scale SERP system used at the Rainbow Disposal site was operated for approximately two years. The system was operated for 16 hours a day, 5 days a week for the first year. A 24-hour cycle of operation, 6 days a week was used for the remaining year. During most of the treatment, steam injection and vacuum extraction were used simultaneously. Vacuum extraction alone was used when the boilers were inoperable, during interim soil sampling activities, and at the end of the remediation. Vacuum extraction used alone after steam injection is expected to dry and cool the soil and remove contaminants from lower permeability soils.

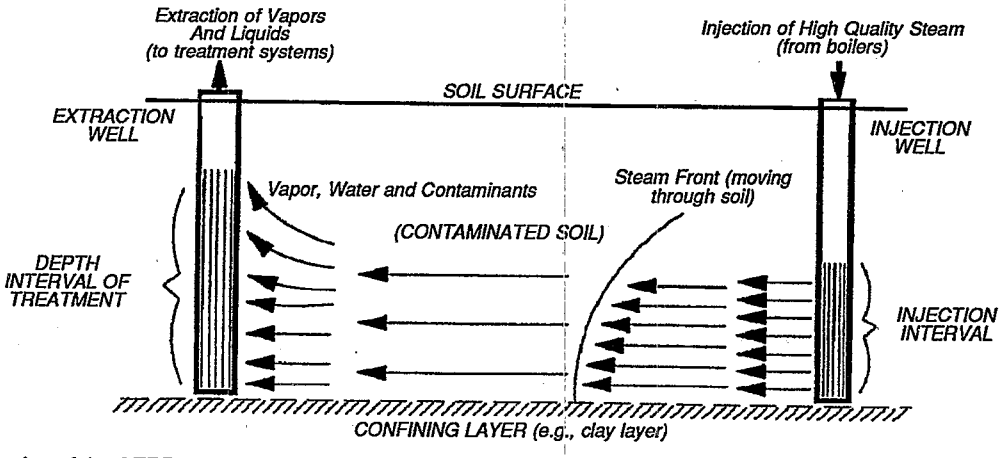

Figure 1. *Conceptual operation of the SERP process beneath the soil surface.*

Demonstration Approach: The U.S. EPA Superfund Innovative Technology Evaluation (SITE) program became involved with the *in situ* SERP technology developer after the system was installed at the Rainbow Disposal site. Pre-treatment soil sampling and analyses occurred prior to full SITE program participation. Therefore, the focus of the Demonstration was on the condition of the soil after treatment to determine if the technology met the site-specific cleanup criterion of 1,000 mg/kg (ppm) of total petroleum hydrocarbons (TPH, diesel). An economic analysis of the system was also a primary objective for the Demonstration.

Before treatment, one to four samples from each of twelve boreholes within the defined perimeter of contamination were sampled by the technology developer and analyzed for TPH and benzene, toluene, ethylbenzene, and xylenes (BTEX). The pre-treatment results will be used by the SITE Program in a non-critical evaluation of the removal efficiency of the treatment.

The SITE program (EPA) performed post-treatment soil sampling and analyses, including sampling from boreholes adjacent to (within four feet) and at the same depths as those sampled before treatment. Additional samples at other depths were collected in most of these boreholes. Twelve additional boreholes were also sampled, including six outside the defined perimeter of contamination for a total of 24 boreholes. Samples collected after treatment were analyzed for TPH, BTEX, and total recoverable petroleum hydrocarbons (TRPH). Six sets of triplicate samples were collected at randomly determined sampling locations to assess soil contaminant spatial variability. The data collected from post-treatment sampling and analysis has been used in a geostatistical model to determine the likely distribution of contamination remaining in the soil and the statistical significance of the results.

A detailed economic analysis of this full-scale technology application will be performed utilizing monitoring data (i.e., water, chemical, and gas usage; waste generation; and maintenance needs). This data was collected by the developer with oversight by the SITE program during the course of operation. This analysis will focus on the actual costs of the full-scale remediation as well as theoretical costs at another site.

Preliminary Results: Preliminary evaluation of the post-treatment data suggests the following conclusions:

- The geostatistical weighted average soil TPH concentration in the treatment area after treatment was 2,290 mg/kg. The 90 percent confidence interval for this average concentration is 996 mg/kg to 3,570 mg/kg, which shows that there is a high probability that the technology did not meet the cleanup criterion. Seven percent of soil samples had TPH concentrations in excess of 10,000 mg/kg.

- The geostatistical weighted average soil TRPH concentration was 1,680 mg/kg with a 90 percent confidence interval of 676 mg/kg to 2,680 mg/kg. Levels of BTEX were below the detection limit (6 µg/kg) in post-treatment soil samples; BTEX was detected at low mg/kg levels in a few pre-treatment soil samples.

- Analysis of triplicate samples showed marked variability in soil contaminant concentration over short distances. Analogous results for TPH and TRPH triplicate samples suggest that the contaminant concentration variability exists within the site soil matrix and is not the result of analytical techniques. This inhomogeneity is the reason that confidence intervals for the average concentrations are so large.

- The data suggests that lateral or downward migration of contaminants did not occur during treatment.

Key findings from the demonstration, including complete analytical results and the economic analysis, will be published in an Innovative Technology Evaluation Report. This report will be used to evaluate the *in situ* SERP technology as an alternative for cleaning up similar sites across the country. Results will also be presented in a SITE Technology Capsule and a videotape.

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